Improving Air-Sea Coupling Parameterizations in High-Wind Regimes

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LONG-TERM GOAL

The long-term goal of this PI team is to understand the physical processes of the air-sea interaction and coupling of the atmosphere-ocean system in high-wind maritime regimes, with a particular emphasis on hurricanes. One of the most complex aspects in the air-sea coupling is the effect of surface waves at the air-sea interface that is not clearly defined in the high-wind conditions. We aim to determine the changes that must be made to the coupled atmosphere-wave-ocean models in order to simulate the coupled boundary layers under extreme wind conditions.

OBJECTIVES

The specific objectives of this study are to 1) develop and test a new parameterization of wind-wave coupling in high-wind conditions, 2) test the sensitivity of the ocean mixed layer (OML) structure and dynamics to various mixing schemes in high-wind conditions, 3) improve hurricane intensity forecasts using in a high-resolution, fully coupled atmosphere-wave-ocean modeling system and evaluate the model results using observations from the Coupled Boundary Layer Air-Sea Transfer (CBLAST) field program, and 4) explore the impacts of a new sea-spray parameterization using wave energy dissipation on air-sea fluxes and hurricane intensity.

APPROACH

Our current focus is to study the nature of coupled atmosphere-ocean boundary layers and heat and momentum exchange at the air-sea interface in hurricanes. We develop improved parameterizations of subgrid-scale processes, air-sea exchange coefficients, and surface fluxes in coupled atmosphere-wave-ocean models with high-resolution (~1-2 km grid spacing) that can resolve the hurricane eyewall structure. The RSMAS/UM PI team is focusing on the effects of ocean wave “spectral tails” on drag coefficient, wind-wave coupling, sea-spray parameterization using wave energy dissipation, and ocean mixed layer parameterizations. In a closely related project (supported by ONR under grant N00014-03-1-0473), the PI (Chen) worked with Drs. W. Frank and J. Wyngaard at PSU to develop improved parameterizations of subgrid-scale processes in ABL. The methodology is to use a Large-Eddy Simulation (LES) initialized for hurricane-like conditions, including very high winds, sea spray, and the effects of waves at the lower boundary. In collaboration with Drs. Fairall and Bao at NOAA, we have developed and tested a new sea-spray paramterization using the wave energy dissipation. These parameterizations would then be installed and tested in the coupled atmosphere-wave-ocean models like the coupled modeling system at RSMAS/UM and the U. S. Navy’s COAMPS in the near future.

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14. ABSTRACT
The long-term goal of this PI team is to understand the physical processes of the air-sea interaction and coupling of the atmosphere-ocean system in high-wind maritime regimes, with a particular emphasis on hurricanes. One of the most complex aspects in the air-sea coupling is the effect of surface waves at the air-sea interface that is not clearly defined in the high-wind conditions. We aim to determine the changes that must be made to the coupled atmosphere-wave-ocean models in order to simulate the coupled boundary layers under extreme wind conditions.

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We have also worked closely with the PI team (Drs. Black, Drennan, Sanford and others) taking observations during the CBLAST-Hurricane field program and using the data to evaluate/validate our coupled modeling results.

WORK COMPLETED

During the year 2006-07, we have complete the development and testing of the CBLAST wind-wave coupling parameterization for the next-generation high-resolution fully coupled atmosphere-wave-ocean model for tropical cyclone research and predictions. We have also conducted a number of coupled model simulations to develop and test a new sea-spray parameterization using wave energy dissipation, which is done in collaboration with Drs. Fairall and Bao. Here we summarize the major accomplishments by the PI team:

- A new wind-wave parameterization for fully coupled atmosphere-wave-ocean model developed under the CBLAST-Hurricane is tested and documented in Chen et al (2007a, 2007b, and 2007c).

- Completed the evaluation/validation of the wind-wave coupling parameterization by comparing the coupled and uncoupled model simulations of Hurricane Frances (2004) with detailed analyses of CBLAST observations including the airborne radar, GPS dropsonde, sea states, upper ocean temperature and current, and turbulence flux measurements.

- Examined the sensitivity of hurricane simulations in the ocean model to the OML parameterizations in collaboration with Dr. Jim Price of WHOI and compared the results with the best upper ocean observations in Hurricane Frances (2004) by Sanford et al. during CBLAST-Hurricane field program.

- Tested various mixing schemes in HYCOM and their influence on upper ocean temperature and currents in the Gulf of Mexico during the passages of Hurricanes Isidore and Lili (2002).

- Worked in collaboration with other CBLAST PIs, including the PSU group, Drs. Chris Fairall and J-W Bao of NOAA and Dr. Shouping Wang of NRL to include the effects of surface waves and an improved sea-spray parameterization in the coupled model. Melicie Desflots, a graduate student working with Dr. Chen at RSMAS/UM, has completed her Ph.D. dissertation to examine the impacts of these coupling parameterizations on air-sea fluxes and hurricane intensity (Desflots 2007).

RESULTS

The scientific findings have been summarized in Chen et al. (2007a, 2007b, 2007c), Zhao and Chen (2006, 2007), and Desflots (2007). Here we highlight some major results: UM-CHM (University of Miami-Coupled Hurricane Model)

1) A new CBLAST wind-wave coupling parameterization

The coupling of the atmosphere through waves to the ocean is best served by a direct calculation of the evolution of the wave field and the concomitant energy and momentum transfer from wind to waves to upper oceanic layers. Existing third generation wave prediction models are unable to do this as their shortwave cut-off is about 10-30 m wavelength while most of the stress is supported by shorter waves. In order to correct this short-coming a new wave and wind stress prediction model has been developed and is being tested against field and laboratory data with respect to its wave and stress prediction skill in rapidly changing wind conditions against direct measurements of wave spectra and Reynolds stress. The new wind-wave parameterization calculates directional stress using surface wave directional spectra by parameterizing "spectral tails" (wavelength < 10 m) unresolved by the current wave models (Chen et al. 2007a). One of the issues regarding to the prediction of hurricane intensity changes is the ratio of the enthalpy and drag coefficients (C_k and C_D). Using a simple axisymmetric model with idealized environmental conditions, Emanuel (1995) has proposed that the ratio needs to be at least equal or greater than one for hurricane to intensify. However, the lab experiments of high-winds have shown that the C_D value is max out at high-wind speeds as a process referred to as the "flow separation" occurs (Donelan et al. 2004). Recent airborne turbulence flux measurements from the CBLAST-Hurricane (e.g., Black et al. 2007, Drennan et al. 2007, French et al. 2007) also support the lab results indicating that this ratio is less than one for intensifying storms such as in Hurricanes Fabian (2003) and Frances (2004).

2) Coupled simulations and comparisons with CBLAST observations

We have conducted a number of fully coupled atmosphere-wave-ocean model simulations to investigate the sensitivity of model simulated hurricane intensity to various coupling parameterizations. Figure 1 shows an example of the fully coupled model simulation of rain, ocean surface temperature and current compared with that observed fields in Hurricane Frances during the CBLAST field program in 2004. An overview of the results from the CBLAST-Hurricane have been published (Chen et al. 2007 and Black et al. 2007) in a special issue in BAMS.

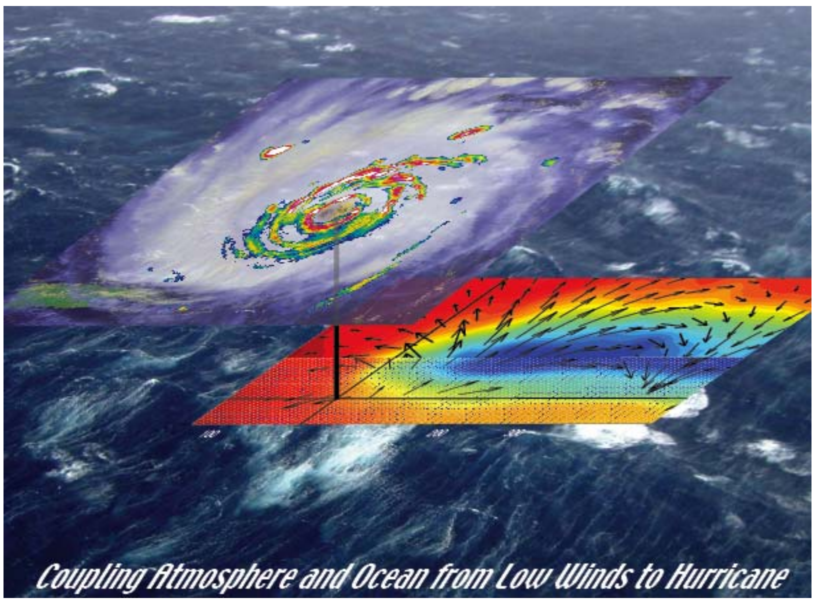

Figure 1 Comparisons of the coupled model simulated rain rate and (upper half) and the NOAA P3 airborne radar observed reflectivity (lower half) in the top embedded image, and the SST cooling and surface currents from the coupled model (upper half) and observations (lower half) in the bottom embedded image in Hurricane Frances (2004), respectively. The observations of SST cooling and surface currents are from three EM-APEX floats deployed near the Caribbean Islands before the passage of Frances.

3) Improving hurricane intensity forecasts

The coupling to the ocean circulation model improves the storm intensity by including the storm-induced cooling in the upper-ocean and SST, whereas the uncoupled atmosphere model with a constant SST over-intensifies the storms as shown in the minimum sea-level pressure (MSLP) (Fig. 2). However, without coupling to the surface waves explicitly, both the uncoupled atmospheric model and the coupled atmosphere-ocean model underestimate the surface wind speed, even though the minimum sea-level pressure of the atmosphere-ocean coupled model is close to the observed values. The pressure-wind relationship is an important forecasting issue. Although the MSLP is a good measure of hurricane structure throughout the deep troposphere, the maximum surface wind is what operational forecasters use to warn the potential damage by hurricanes of various intensities. Figure 3 shows the comparison of the model simulated pressure-wind relationship compared to that observed in the Atlantic basin over the last 150 years. The full coupling with the CBLAST wave-wind parameterization clearly improves the model simulated wind-pressure relationship that is a key issue in hurricane intensity forecasting. The improved wind-pressure relationship is showed in all the simulated hurricanes documented in Chen et al. (2007b, 2007c).

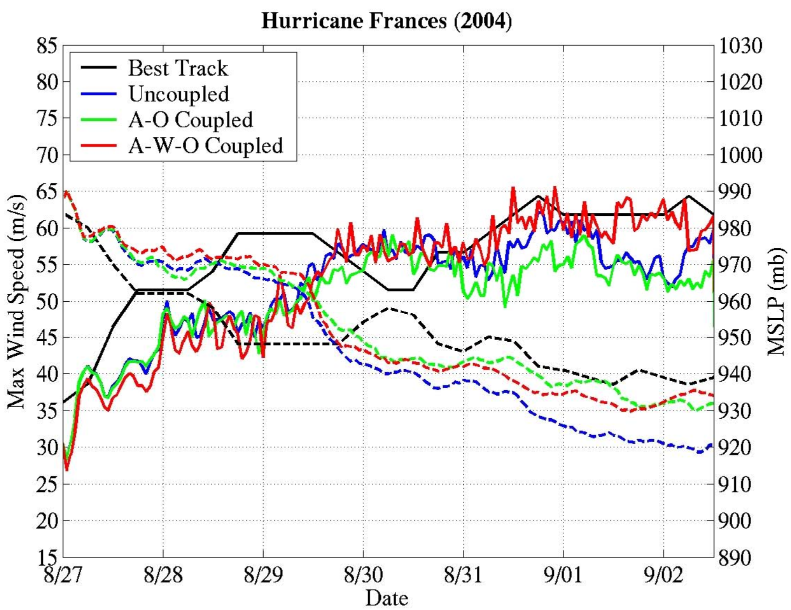

Figure 2 Observed (the NHC best track data in black) and simulated MSLP (dashed lines) and maximum wind speed (solid lines) from the fully coupled atmosphere-wave-ocean model (red), coupled atmosphere-ocean model (green), and uncoupled atmosphere model (blue), for Hurricanes Frances from 0000 UTC 27 August – 1200 UTC 2 September 2004.

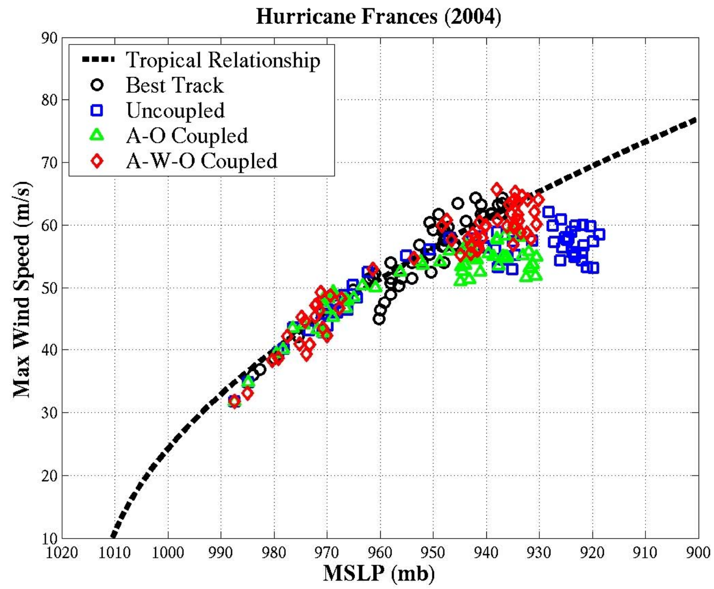

Figure 3 Observed (the NHC best track data, black circles) and simulated pressure-wind relationship from the fully coupled atmosphere-wave-ocean model (red), the coupled atmosphere-ocean model (green), and the uncoupled atmosphere model (blue) for Hurricanes Frances.

IMPACTS/APPLICATIONS

Recent reports from the NOAA Science Advisory Board Hurricane Intensity Working Group (http://www.sab.noaa.gov/Reports/HIRWG_final73.pdf) and the National Science Board task force on hurricane science and engineering (http://www.nsf.gov/nsb/committees/hurricane/initiative.pdf) have both identified that improving hurricane intensity forecasts as the highest priority for hurricane research community. The reports have also cited the recent science results from the CBLAST-Hurricane program as a key to develop the next-generation hurricane prediction models. The PI (Dr. S. Chen) was invited as an expert on the Panel of Experts in July 2007 to brief the US Congress and Senate on the Capital Hill on the development of the National Strategy for the future of hurricane forecasting.

This project has and will continue to provide improved physical parameterizations for the coupled atmosphere-wave-ocean models at very high spatial resolution. It will make a significant contribution to improve tropical cyclone predictions around world, which is a great importance to the US Navy operations. The fully coupled atmosphere-wave-ocean modeling framework developed by this PI team (in collaboration with other ONR supported CBLAST colleagues) will provide not only high-resolution forecasts of extreme winds and rainfall, but also the extreme surface waves and ocean current and temperature in hurricane conditions.

TRANSITIONS

We will assist in the transition of the completed CBLAST wind-wave parameterization to operational coupled modeling systems including the Navy Coupled Ocean and Atmosphere Model Prediction System (COAMPS) and Hurricane Weather Research and Forecast (HWRF) model. We plan to have a post-doctoral research associate working at NRL-Monterey and RSMAS/University of Miami on the coupling parameterization and testing in COAMPS.

FUTURE RESEARCH

One of the unresolved issues is the representation of enthalpy fluxes in high wind conditions in the fully coupled models. The difficulties include the lack of observations and surface flux parameterization with effects of sea spray. This PI team is currently working in collaboration with Dr. Chris Fairall of NOAA to develop a new enthalpy flux parameterization linking wave breaking/energy dissipation directly to spray generation.

RELATED PROJECTS

Related projects include the funded NSF RAINEX on hurricane rainbands and intensity change (S. Chen), the NASA/JPL QuikSCAT Science Team on data assimilation of the surface winds in tropical cyclones (S. Chen), the NRL-Monterey CBLAST-LOW modeling (J. Doyle and S. Wang), and the ONR CBLAST-Hurricane Observations (P. Black et al.).

PUBLICATIONS (2007)

Chen, S. S., J. F. Price, W. Zhao, M. A. Donelan, and E. J. Walsh, 2007a: The CBLAST-Hurricane Program and the next-generation fully coupled atmosphere-wave-ocean models for hurricane research and prediction. *Bull. Amer. Meteor. Soc*, **88**, 311-318.

Chen, S. S., W. Zhao, M. A. Donelan, 2007b: A wind-wave coupling parameterization for high-wind conditions. *J. Atmos. Sci.*, submitted. (Available at http://orca.rsmas.miami.edu/~schen/publications/)

Chen, S. S., W. Zhao, M. A. Donelan, J. F. Price, E. J. Walsh, T. B. Sanford, and H. L. Tolman, 2007c: Fully coupled atmosphere-wave-ocean model simulations of Atlantic hurricanes. *J. Atmos. Sci.*, submitted. (Available at http://orca.rsmas.miami.edu/~schen/publications/)

Davis, C., W. Wang, **S. S. Chen**, Y. Chen, K. Corbosiero, M. DeMaria, J. Dudhia, G. Holland, J. Klemp, J. Michalakes, H. Reeves, R. Rotunno[1], and Q. Xiao, 2007: Prediction of landfalling hurricanes with the Advanced Hurricane WRF Model, *Mon. Wea. Rev.*, in press.

Desflots, M., 2007: Environmental and internal influence on hurricane structure and intensity change. Ph.D. dissertation, University of Miami, pp 187.

Rogers, R., M. Black, **S. S. Chen**, and R. Black, 2007: Evaluating microphysical parameterization schemes for use in hurricane environments. Part I; Comparisons with observations. *J. Atmos. Sci.*, **64**, 1811-1834.